Future challenges in food and agriculture:
Science informing policy

Potential contribution of advances in photosynthesis to plant productivity and global food production

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• **What is problem of crop productivity for food security?**
  – decreasing yield growth of major crops
  – increasing shortfall of food production for increasing population
  – increasing cost of food and increasing food insecurity
  – increasingly limited agricultural resources, esp. land, water and N-fertilizer

• **What are options for increasing crop productivity?**
  – only minimal further gains from breeding for biotic stresses possible
  – need for quantum leap in productivity not just incremental; second green revolution
  – improving photosynthetic capacity is best option

• **What is photosynthesis and why is it the best option?**
  – definitions, use of free resources and possibilities to reduce costly limited resources

• **Translating photosynthesis research into more productive crops**

• **Checklist: technological, economic and sociopolitical issues**

• **Possible questions for policy makers and discussion**
Problem of crop productivity: decreasing yield growth

• Mere handful of crop plants sustain human and animal populations, world-wide.

• But rate of increase in global productivity of all major food crops (maize, wheat, rice, soybean and roots and tubers) has declined greatly over the last 20 years while world demand for food continues to increase.

• Further gains at similar rates of increase are insufficient to ensure future food security – with projected population growth to 9 billion people by 2050.

Average improvements in global productivity are declining.
Increased cost of food staples; peaks in 2008 and 2011

- Increasing mismatch between food supply and demand led to escalating food prices recently.
- Factors, such as energy and fertilizer costs, diversion of land, and grain and other crops, to biofuel production and urbanization, are exacerbating food shortages and cost increases.

*Real price index is nominal price index deflated by World Bank Manufactures Unit Value Index (MUV).

FAO Food Price Index as of 7 July ’12. Index consists of average of 5 commodity-group price indices (meat, dairy, cereals, oils & fats, sugar) weighted with average export shares of each of groups for 2002-2004).
World’s population is expected to exceed nine billion by 2050. Current farming resources are already stretched to their limits. **Second Green Revolution.** Step change in productivity needed for expected demand.
Increasingly limited resources: land, water, fertilizer

- Pressure on land for food-crop agriculture from urbanization and diversion to industrial crops.
- Increased cost of N-fertilizer as energy-expensive production.
- Limitation on water resources coupled with apparently increasing droughts.
- Peak phosphorus.

Not much uncultivated land* left: latest estimates in million hectares

<table>
<thead>
<tr>
<th>Region</th>
<th>Share of spare land with travel time to market &lt;6 hours, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-Saharan Africa</td>
<td>47</td>
</tr>
<tr>
<td>Latin America &amp; Caribbean</td>
<td>76</td>
</tr>
<tr>
<td>Eastern Europe &amp; Central Asia</td>
<td>83</td>
</tr>
<tr>
<td>East &amp; South Asia</td>
<td>23</td>
</tr>
<tr>
<td>Middle East &amp; North Africa</td>
<td>87</td>
</tr>
<tr>
<td>Rest of world</td>
<td>48</td>
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</tbody>
</table>

* High agro-ecological potential and population density < 25 persons/km²


Annual average nutrient (NPK*) applications to arable land: 1997-1999

* nitrogen, phosphorus, potassium

from Bruinsma (2003) using FAO data
Regional shares of global increase in NPK fertilizer 2011-2015

Consumption

Problem for Asia

Supply

nitrogen (N)

phosphorus (P)

potassium (K)

from FAO (2011) Fertilizer trends report
European solution: add more nitrogen!!!!!

Fertile ground: “Broadbank”
average wheat yields (tonnes/hectare)

Actual and agro-ecologically attainable yields for wheat in selected countries

*with too little nitrogen
† for maximum yield
‡ plus spring nitrogen

from www.economist.com/node/18200618
(2011) using Rothamsted Research data*
Options for increasing crop productivity?

- Current small, incremental gains in plant productivity have come from plant breeding to improve resistance to stress – drought, cold, high salinity, pests and diseases – and improvements in water and fertilizer use efficiency.

- But further gains at similar rates of increase will be insufficient to ensure future food security. A second step change in plant productivity – of scale of success of Green Revolution of 1960s – is now required.

- The next ‘wave’ in agricultural technology requires a fundamental improvement in the green plant’s capacity to grow more vigorously.

- But has to be achieved in a world increasingly limited by availability and cost of “inputs” – water, fertilizer and arable land –, and climate change uncertainties.

- Improving photosynthetic capacity of plants is best option to target increases in yield potential of crops while minimizing demands on inputs.

[Reaping the benefits: science and the sustainability intensification of global agriculture, The Royal Society, 2009.]
Photosynthesis – earth’s elixir of life

- Photosynthesis underpins yield and crop production.

- Process by which plants and other photosynthetic organisms use sunlight to capture CO₂ and convert it into sugars and biomass for growth.

- Free and abundant inputs! – light and CO₂ (increasing!)

- Photosynthesis underpins virtually all life on earth but its efficiency is often limited by rate of conversion into chemical energy in chloroplasts of plant leaves and subsequent transformation into sugars and biomass.
Two types of photosynthetic processes:
light capture and sugar reactions

- Maximum efficiency for conversion of solar energy to biomass by plants is <6%
- Reduction to ~40% after light reactions
- Reduction to ~10% after sugar reactions
  [Xhu et al. (2008) Curr Opin Biotech 19, 153-159]
- Latter loss of ~30% largely due to inefficiency of Rubisco. As result, Rubisco is up to 50% of leaf nitrogen (N) – most abundant protein on earth.
- Water is lost from leaves.
- Efficiency and plant growth sensitive to temperature (T), water and light intensity
- ANU technology provides possibility to improve photosynthetic efficiency and reduce water and N requirements.
Huge scale of photosynthesis in the global carbon cycle

Additional carbon released into atmosphere due to burning of fossil fuels

Carbon assimilation due to Rubisco activity

Carbon acquired by Rubisco activity in the distant past

* 1 petagram = 1 billion tonnes
Translating photosynthesis research into more productive crops

Some key considerations for translation

- Projected impacts of climate change
  - Recent IFPRI Report has alarming projections of scale and uncertainty of yield changes from 2000 - 2050 in major crops. [G.C. Nelson et al., IFPRI, 2009.]
  - These changes will impact developing-world regions most negatively. Food crops in South Asia large yield declines (wheat by 20-30%). Maize yields in sub-Saharan Africa much lower.
  - Funding increase of $7 billion pa to counteract effects on nutrition in developing countries. Additional $1.4 billion needs to be spent on agricultural research.

- Different needs of farmers: poor and commercial, developing and developed countries
  - Both need more resilient crops that reliably yield a crop under adverse conditions, and minimize expensive inputs. Geographically, different agro-climatic conditions (T, water).
  - But crop reliability is critical for poor farmers for food security and poverty reduction, and debt avoidance.
Some key considerations for translation cont.

Ownership of crop-development technology

Multinational agbiotech companies have increasing dominance in developing new varieties of broad-acre crops, including food-staple cereals.

Imperative for ensuring technology ownership allows IP access to develop new “best” crop varieties for poor farmers in developing countries – who aren’t commercial markets.

Need for new strategies to ensure IP from publicly funded research remains available for use in not-for-profit and international aid sectors.

– Direct negotiation, as for arrangements under ANU’s Agreement (2011) with BayerBioscience for IP licensing of its Rubisco re-engineering patent.

– Other models for ensuring access?

Importance of agriculture for poverty reduction: how for best result?

Agriculture (52%) dominates non-agriculture by potential to reduce poverty among the poorest of the poor, whether the comparison is within or between countries. [OECD report, 2011 www.oecd.org/agriculture.]
CHECKLIST

• Assuring food security not just a technological problem: major socio-political implications for civil disturbance and mass displacement/migration of tens of millions of people.

• Technological solutions need to be sensitive to cultural issues of food, including consumer acceptance, and nutritional value - not just calories.

• Differing interests of urban and agrarian populations in developing countries.

• Food security inextricably linked with other major global issues: energy, climate change, water, arable land, fertilizer, so technological solutions for improving crop productivity and food security must simultaneously address them.

• Geographically, winners and losers from projected effects of climate changes on crop productivity. Developing country regions with large, increasing populations (Asia and Africa) appear major losers.

• Different solutions for increasing crop productivity in developed countries of northern hemisphere (wetter, cooler, lower light) and developing and transition countries, but also Australia (increased northern agriculture?).

• Need to consider environmental sustainability and biodiversity.

• Need to ensure IP access for not-for-profit applications of publicly funded research.
Possible questions for policy makers and discussion

- How do Australian policy makers deal with complex, and often incompatible, drivers for policy development for higher education and research training, S&T research and innovation, agricultural R&D, international aid, trade and foreign affairs?

- How can Australian researchers grasp how the policy development process “works” and provide timely and effective input?

- Best ways for policy makers to obtain timely primary input from researchers on groundbreaking research with potential for quantum-jump applications for economic and social benefit? [For reference: commercial bodies such as biotech companies adopt a proactive role in scouting out the best new science.]

- For cases such as presented here, i.e. increasing crop productivity for targeted benefit, commercial and public good, and nationally and internationally, how can Government departments with above different briefs co-operate to provide funding for a comprehensive R&D program for whole pipeline from basic research to delivery of appropriate products to end-users?
...so not only will the money tree store carbon, but it will also easily pay for the scientific research required to develop the money tree technology.

And to think I wasted all that money on Ross Garnaut.

Have you modelled Tony's direct action model yet?

I've tried, but the computer keeps asking for the punchline.
US Policy statement 1973
Left, NOAA Environmental Research Laboratories (ERL)
Right, NOAA Operational Activities
Top, NOAA Management

The result sometime later......